Screening of french mining exploitations : a methodology and a national hierarchisation to evaluate the geotechnical risk

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SCREENING OF FRENCH MINING EXPLOITATIONS: A METHODOLOGY AND A NATIONAL HIERARCHISATION TO EVALUATE THE GEOTECHNICAL RISK

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ABSTRACT : The French Ministry, in charge of mining and post-mining issues, plans to perform as effectively as possible its future investigations (Mining Risk Prevention Plans, MRPP, in particular). In this way, an ambitious program, called Screening, has been engaged in order to classify and to evaluate all French mining sites according to their mining risk level and then, to perform a quick risk evaluation for the most critical sites. This process included an important stage of hierarchisation. After many months of works, a multi-criteria analysis (based on ELECTRE's method) was finally adopted. It required an appropriated selection of experts, an effective criteria definition, use of adapted tools and a precise validation before application to given mining sites. The different steps of this work are presented in this paper.

KEYWORDS: Multi-criteria analysis, mining risk, hazard, hierarchisation, ELECTRE's methods, Screening, ground instabilities.

RÉSUMÉ: Le Ministère en charge, en France, de la gestion des problèmes miniers tente de planifier le plus efficacement possible ses futures études (Plans de Prévention des Risques Miniers, PPRM, notamment). Pour ce faire, un programme ambitieux, baptisé Scanning, a été engagé afin de classer et d'évaluer les risques, liés aux exploitations minières, de potentiels mouvements de terrains. Ce processus comprend une phase importante de hiérarchisation. Après de mois de réflexions, c'est une analyse de type multicritères (de la famille des méthodes ELECTRE) qui a finalement été retenue. Cette hiérarchisation nécessite de faire appel à un groupe d'experts, de définir des critères de hiérarchisation efficaces, d'utiliser des outils adaptés et de valider précisément chacune des étapes avant d'envisager de hiérarchiser des sites miniers. L'article suivant présente la démarche complète de cette mise en oeuvre.

MOTS-CLEFS: Hiérarchisation multicritères, risques miniers, aléas miniers, méthodes ELECTRE, Scanning, mouvements de terrains.

1. Contexts and goals

Because of its rich industrial past and its long mining tradition, more than 4000 mining titles (concessions, exploration agreements) have been granted throughout the whole metropolitan French territory in very different geological configurations. Nowadays, under the effect of diminishing resources and the international competition, most French mining operations are gradually forced to close and only few mines (salt mines) are always exploited. The main issue is to manage these old mining workings, often identified as a source of nuisance that can affect lands, during the post-mining period. In France, it is the State responsibility to evaluate and to report the residual mining risks (surface instability, flooding, dangerous gas emission, dangerous ground or water pollution, ionizing radiation).

To draw up rules for managing land use according to the various constraints linked to these mining risks and nuisances, the French State has acquired an operational regulatory tool : Plans de

Prévention des Risques Miniers (PPRM) (Mining Risk Prevention Plans - MRPP). Between 1999 and 2007, MRPP have been engaged in the main mining ore basins exploited in France : certain metal mines (copper in Alps, uranium in Centre-West, etc), major iron ore fields (Lorraine, Centre-West), many coal basins (Provence, Centre-South, etc). The study of the major salt basins (Lorraine, Jura, South-West) is programmed for 2008. Taking into account this trend of MRPP implementation, one can easily estimate that MRPP are very long studies. It was essential to define, in a short period of time, the sites that present the most significant post-mining risks in order to assist the State in his land management. Another goal is to establish priorities in the implementation of the future MRPPs (the most sensitive sites could be treated prior to the others). It was also important to identify quickly the critical contexts requiring urgent safety measures.

Hence, the French Ministry, in charge of mining management, asked to carry out simple risk qualification by focusing on surface instabilities. This ambitious program, called "Mining Sites Screening Process", consists in :

- reviewing all French mining sites in order to classify them according to their risk level (considering surface instabilities) ;
- selecting the most sensitive mining exploitations and to subject them to quick studies in order to evaluate and to map risk and hazard levels linked with land movement (gradual subsidence, local cave-in, etc). The other phenomena (gas emission, dangerous ground or water pollution, etc) are not considered in detail in these studies. They will be only mentioned in case they are observed.

This paper details the whole steps that allowed to classify mining sites : determination of a classification methodology, construction of hierarchisation tool, validation, analysis of different issues.

The paper is devoted to the first point of the Ministry demand. The second aspect (risk analysis in the most sensitive mining sites) will not be presented here because many other papers have investigated to this topic [(DIDIER and LELOUP, 2005) and (DIDIER and JOSIEN, 2003)].

2. Development of a selection methodology and construction of a hierarchisation tool

2.1. Hierarchisation methodology

Mining operations consist in extracting large quantities of ore, only a valuable part of the great amount of excavated rocks. These excavations (underground or open-cast) have irreversibly altered the rock formations in which the ore is found and their stability could be threatened at long term. These instabilities could generate disorders at surface (different kind of subsidence events) resulting in damages to structures and potentially dangers for people. The Screening ought to help their evaluation.

The post-mining risk management is based on various knowledge. Many actors and experts have been called to contribute to this risk selection. Like the elaboration of methodological guideline for the elaboration of MRPPs, the methodological works of the Screening were established with the help of an expert college functioning as a steering committee (DIDIER, 2006). It was composed of mining experts and professionals of geotechnical analysis : BRGM, INERIS, Mining School of Paris and GEODERIS (with JP. JOSIEN who was the organizer of the national experts committee studying land movements for the MRPP methodological guideline elaboration).

In the first time, when the experts have been questioned, more than 10 criteria have been listed in order to evaluate post-mining risks, they were linked with factors of surface vulnerability, significance of effects and susceptibility of underground mining works to collapse. With the experience of the experts committee and taking into account the complex evaluation of mining risks and hazards, it was agreed to use methods and tools based on multi-criteria analysis.

The Screening was expected to provide with a global classification of all the known mining sites. For this, a multi-criteria Expert-Aid method has been proposed, it was based on ELECTRE III method (MERAD, 2004), (FIGUEIRA, MOUSSEAU and ROY, 2005). Indeed, these methods have to generate a classification in a determined sample of mining sites described according to a revelant criteria family (quantitative or qualitative). ELECTRE III allows to classify mining sites from the best to the worst (from the more risky to the less risky). Moreover, these methods have been successfully applied to the mining risk management in Lorraine region (East of France) since 1999 (POULARD and SALMON, 2002). Taking into account all these elements ELECTRE III was finally adopted.

2.2. Criteria definition and evaluation

ELECTRE III method requires to define a list of criteria, constituting a basis for the classification. In the Screening, the goal is to select mining sites according to their potential *risk* level linked with ground instabilities. Therefore, this *risk* results from the crossing of :

- the existence of a land movement hazard. This idea is based on the evaluation of site's predisposition to be affected by any kind of instabilities (combination of different factors that are favourable or unfavourable to the initiation and to the development of an underground collapse). Moreover, in the Screening, mining hazards involved the quantification of the feared events consequences (size and numbers of disasters…) ;
- the existence of human land occupation (constructions, equipment and infrastructures). It aims to characterise the existing vulnerability and to identify the potential future projects which could develop within these areas (main construction projects : allotments projects, etc).

In this regard, 2 criteria groups have been defined. The first tries to give information on mining hazards and the second is linked with the land occupation.

The experts have defined qualitative criteria. They inform on the criteria after an experimental evaluation or an extrapolation, using similarities between mining sites. These qualitative definitions are based on the identification of homogeneous risk levels. For instance, to describe the "geological overburden nature", mining sites were distributed in three levels : weak, fairly strong and strong. That is to say the mining sites could present three similar probability levels of underground workings instabilities (Table 1).

The nature and the quality of mining information available have oriented this criteria definition. Indeed, the information was collected in GEODERIS mining site GIS-assisted database or in Departmental Archive database ; thus, it was useless to establish criteria that could not be informed because missed in databases.

2.2.1 Mining hazard criteria definition

In the Screening hierarchisation, the hazard linked with land movements potentially generated by underground mining works, is described through three phenomena (the most sensitive disorders that may persist at long term in the surroundings of former mining French works) (Didier, 2006).

These three phenomena are :

- gradual subsidence (gradual, flexible readjustment of surface layers) ;

Table 1. Mining hazard criteria (gradual subsidence and local cave-in)

Criteria C_i	Description	Modalities or values
Ore mechanical strength	5 MPa (manganese, coal, sulphur…)	TEND
	20 MPa (bauxite, oil shales, fluorite, anthracite, salt…)	MOYR
	100 MPa (lead-zinc-silver, copper…)	RESI
Fields typology	stratiform (deposit layer)	STRAT
	cluster	AMAS
	lenses (maximal extension 50 m)	LENT
	seams	FILO
	disseminated or diffuse	DISS
Mining method used	rooms and pillars and void rooms	VIDE
	insulated galleries	GISO
	longwall or backfilling	TRF
	open pit works	MCO
Void percentage	value in en % growing with the risk level	quantitative
Maximum depth of workings	maximum depth $\in$ [0-50 m]	MDa
	maximum depth $\in$]50-100 m]	MDb
	maximum depth $\in$]100-200 m]	MDc
	maximum depth $\in$]200-500 m]	MDd
	maximum depth > 500 m	MDe
Minimum depth of workings (H_{min})	minimum depth $\in$ [0-50 m]	mDa
	minimum depth $\in$]50-100 m]	mDb
	minimum depth $\in$]100-200 m]	mDc
	minimum depth > 200 m	mDd
Opening of workings	opening < 1 m	Oa
	opening $\in$]1 à 3 m]	Ob
	opening $\in$]3 à 10 m]	Oc
	opening > 10 m	Od
Deformation : opening/H_{min} (gradual subsidence)	quantitative criteria taking values based on growing risk levels (Table 2)	1, 2, 4, 8, 12, 16, 24, 36, 48, 72, 144, 432.
H_{min}/opening (local cave-in)	quantitative criteria taking values based on growing risk levels (Table 3)	2, 5, 15, 30, 75, 100.
Exploitation dip angle	flat (layers) : 0-20°	PLAT
	inclined : 20- 45°	INCL
	sub-vertical : > 45°	PENT
Geological overburden nature	weak : sand, gravel …	MEUB
	fairly strong : schist, marl, chalk…	MOYC
	strong : gneiss, granit, dolomite …	COMP
Presence of shafts or galleries	< 10 shafts or galleries could be listed	NON
	> 10 shafts or galleries could be listed	OUI
Existence of disorders	no known disorder	NON
	At least than 1 known disorder	OUI

- local cave-in (sudden appearance on the surface of a sink-hole). The sudden feature of the instability makes these potentially dangerous events ;
- general cave-in (collapse of all or part of surface, often dynamic). These phenomena are potentially very dangerous.

Table 2. Deformation criteria values (gradual subsidence)

		Opening			
		Oa : < 1 m	**Ob : 1 to 3 m**	**Oc : 3 to 10 m**	**Od : > 10 m**
Minimum depth.	**mDa : 0-50 m**	12	48	144	432
	mDb : 50-100 m	4	16	48	144
	mDc : 100-200 m	2	8	24	72
	mDd : > 200 m	1	4	12	36

Table 3. Minimum depth (H_{min})/opening values (local cave-in)

		Opening			
		Oa : < 1 m	**Ob : 1 to 3 m**	**Oc : 3 to 10 m**	**Od : > 10 m**
Minimum depth. (H_{min})	**mDa : 0-50 m**	30	15	5	2
	mDb : 50-100 m	75 (local cave-in excluded)	30	15	5
	mDc : 100-200 m	100 (local cave-in excluded)	75 (local cave-in excluded)	30	15
	mDd : > 200 m	Local cave-in excluded	Local cave-in excluded	Local cave-in excluded	Local cave-in excluded

General cave-in is a very specific phenomenon that cannot be integrated in a multi-criteria hierarchisation. This rare kind of ground instability is treated and analysed individually when the hierarchisation, linked with a gradual subsidence, leads a “suspect” mining site.

The experts have defined thirteen criteria in order to determine land movement hazards generated by gradual subsidence and local cave-in (three tables above). They are based on :

- geological factors, linked with failure mechanisms : geological contexts, ore and overburden natures, stress states, etc ;
- mining exploitation factors : mining methods (methods of treatment of the voids after extraction or those allowing the persistence of important significant voids after closure), depth of workings, mining productions, etc.

2.2.2 Definition of land occupation criteria

This group of criteria is essential but difficult to be informed. It includes the localisation of old mining workings (not always precisely known) and the definition of the land occupation. Screening having to be carried out at a national level and every mining sites in France having to be classed homogeneously, so it was agreed to work with recent topographic maps, called Scan25, from NGI (National Geographical Institute). Indeed, this data has a good quality/price ratio with an appropriate scale (1/25000). Other known maps (aerial photography or digitalised data) have not be selected, because they are not available in all regions of France, they are are more expensive and they give a precision of scale, of 1/10000 or 1/2000, useless for the Screening taking into account the uncertain mining sites localisation.

Thus, five criteria were finally defined (Table 4). Note that the “Nature of the land occupation” was defined using data read on the Scan25. The values of this criteria are objective, except for the areas with potential constructions. It contains a certain subjectivity based on the operator evaluation using Scan25 (tourist sectors, towns proximity, weather characteristics, etc). The Screening implementation, between 2005 and the end of 2007, has shown that, in spite of its initial definition, this criterion has been informed homogeneously ; the only little differences have been erased when the information on the mining sites has been checked by an expert with a global view.

Table 4. Land occupation criteria

Criteria C_i	Description	Modalities or values
Nature of documents that helped to draw mining sites limits	limits drawings based on precise workings plans	PTS
	limits drawings based on shafts or galleries	OMJ
	limits uncertain	ENVT
	only the title limits available (concessions, exploration agreements)	TCU
	no geographical localisation	PTC
Mining site area	area $\in$ [0 -10 ha]	A
	area $\in$]10 – 50 ha]	B
	area $\in$]50 – 200 ha]	C
	area > 200 ha	D
Mining site production	old and local small-scale mining sites, exploration workings, small scrapping workings… all mining sites with small productions	MINI
	all others mining sites	AUTR
Nature of the land occupation	exceptional constructions : schools, hospitals, monuments, mains plants, etc	EXCEP
	urban centres and villages	HU
	suburban sectors	ZP
	sectors with by potential constructions	ZEU
	insulated constructions	HI
	motorways, national roads et railways	A
	department roads	RD
	no human land occupation	ABS
Stakes area	quantitative criteria taking values sorted by growing risk levels	quantitative

2.2.3 Definition of modalities and weights values for the criteria

The majority of the Screening criteria is defined qualitatively. ELECTRE’s method requires converting these modalities into *values or codes* in order to operate mathematical calculations. For the Screening, it was agreed to give weights to these codes.

Moreover, the different criteria have not the same weights in the final risk evaluation. Thus, criteria must be balanced ones compared to the others by a weight definition.

These two issues are lead to the same question : in which way to associate values (here integer numbers) with individuals in a finite sample (here modalities or criteria). Traditionally, SIMOS’s methods are used in these scientific issues (FIGUEIRA et ROY, 1998). These methods, also called

"Card's methods", encourage the communication between the experts by :

1. classifying modalities (or criteria) from the more risky to the less risky with the possibility to define ex-aequo ;
2. inserting white cards in order to indicate the levels between modalities (or criteria) classed before ;
3. defining the ratio between the more risky modality and the less risky modality (or criteria).

Simple proportional calculations allow to conclude with the final values (modalities and criteria). In the following, the method applied to the Screening is presented.

Whatever the method used, this stage is commonly organised in two parts : individually (expert) and collectively (experts committee). The first one allows to each expert to give his opinion based on his competence and knowledge. In the second stage, on one hand, the experts share their points of view and, on the other hand, they try to address a single global representation.

2.2.3.1 Modalities values

In order to calculate these values, SIMOS's method has been applied except for the second point. Instead of classing white cards, the experts have preferred answering to the questions like : "*For you, in the evaluation of the mining sites predisposition to a local cave-in, a weak geological overburden is how many times more risky than a strong one ?*". The experts have appreciated this enquiries that seem to be more "scientific" and, above all, more efficient than cards. The exploitation and the determination of values are the same.

The final results, established after crossings all expert opinions, are presented in the following table (Table 5). These values have been brought back to a common base of 100 and they are classed with growing risk levels.

These results mean that if a weak geological overburden is ten times more risky than a strong overburden, then a fairly strong overburden is twice risky than a strong one and eight times less risky than a weak one.

Table 5. Modalities values

Criteria C_i	**Modality**	**Values**
Ore mechanical strength	TEND	100
	MOYR	50
	RESI	0
Fields typology	STRAT	100
	DISS	100
	AMAS	60
	LENT	30
	FILO	0
Mining method used	VIDE	100
	GISO	30
	TRF	0

Criteria C_i	**Modality**	**Values**
Maximum depth of workings	MDa	100
	MDb	30
	MDc	10
	MDd	0
	MDe	0
Minimum depth of workings (H_{min})	mDa	100
	mDb	30
	mDc	0
	mDd	Exclusive

Criteria C_i	Modality	Values
Exploitation dip angle	PLAT	100
	INCL	70
	PENT	0
Geological overburden nature	MEUB	100
	MOYC	20
	COMP	0
Presence of shafts or galleries	OUI	100
	NON	0
Existence of disorders	OUI	100
	NON	0
Kind of documents that helped to draw mining sites limits	PTC	100
	TCU	100
	ENVT	60
	OMJ	40
	PTS	0

Criteria C_i	Modality	Values
Mining site area	D	100
	C	66
	B	33
	A	0
Mining site production	AUTR	100
	MINI	0
Nature of the land occupation	EXCEP	100
	HU	90
	ZP	70
	ZEU	60
	A	40
	HI	20
	RD	0

2.2.3.2 Weights values for the criteria

The same approach, than used for the determination of modalities values, was applied here.

The experts compared and classed criteria into the two groups (mining hazards and land occupations). However, they have distinguished, on one hand, local cave-in, and, on the other hand, gradual subsidence (a same criteria has not got the same weight in the local cave-in evaluation than in the gradual subsidence determination).

The next stage was more complicated, ELECTRE's method requires to compare all criteria between them. This exercise has been very difficult for certain experts and impossible for many others. For instance, no expert has been able to answer to this question : "*In the mining risk evaluation, what is the relative weight between the overburden nature and land occupation nature ?*".

On the other hand, each expert could determine which in mining hazards or land occupation was the most important for the mining risk evaluation and each expert could give a ratio between them.

Combining all these weights, those between criteria in each group and those between the two groups of criteria, the estimation of the final weights has been carried out.

However, the experts did not reach the single representation as it was expected. They did not agree on the determination of the ratio between mining hazards weight and the land occupation weight. Thus, to tend towards a global classification and to continue the Screening, it was agreed to retain three systems of weights according to the three following scenarii (Table 6) :

- scenario 1 : mining hazard is as important as land occupation ;
- scenario 2 : land occupation is twice more important than mining hazard ;
- scenario 3 : mining hazard is twice more important than land occupation.

Table 6. Different weights of criteria in the different scenarii

	Criteria C_i	Weights scenario 1	Weights scenario 2	Weights scenario 3
Land occupation	Kind of documents that helped to draw mining sites limits	4	8	4
	Mining site area	13	25	13
	Mining site production	13	25	13
	Nature of the land occupation	46	92	46
	Stakes area	25	50	25
Mining hazards linked with local cave-in	Ore mechanical strength	2	2	5
	Fields typology	1	1	2
	Mining method used	12	12	25
	Maximum depth of workings	12	12	25
	H_{min}/opening	35	35	69
	Exploitation dip angle	2	2	5
	Geological overburden nature	15	15	30
	Presence of shafts or galleries	7	7	15
	Existence of disorders	12	12	25
Mining hazards linked with gradual subsidence	Ore mechanical strength	12	12	24
	Fields typology	3	3	6
	Mining method used	18	18	35
	Exploitation dip angle	15	15	29
	Geological overburden nature	9	9	18
	Presence of shafts or galleries	3	3	6
	Existence of disorders	6	6	12
	Deformation : opening/H_{min}	35	35	71

2.3. Hierarchisation (ELECTRE's theory)

The goal is not to give in detail here the whole ELECTRE's method but only to underline its principal stages that are partly invisible while ELECTRE's software utilisation. The specific choices made for the Screening are explained here.

Using a comparison of mining sites two to two, ELECTRE's method (MERAD, 2004) allows three kinds of relations :

- mining site x_a is more risky (or preferred) than x_b ;
- mining sites x_a and x_b are indifferent (meaning that it is not possible to define the most or the less risky mining site between x_a and x_b) ;
- mining sites x_a and x_b. are incomparable (meaning that x_a and x_b, present too many different characteristics to be compared).

Finally, ELECTRE gives a partial final classification where the mining sites are sorted with risk rows (integers) : a n-row mining site will have a risk more higher than a (n+1)-row mining site.

ELECTRE's method leaves open the possibility, even rare, that two mining sites could not be compared. This possibility does not seem appropriate to the Ministry in charge of mines who needs a classification method for whole mining sites.

To limit these kinds of incomparability and to give a *global* final classification, it is usual to vary the limiting values defined in ELECTRE's method. This, usually studied for each case of incomparability, could not be generalised to the Screening where hierarchisation must be applied homogeneously to thousands of mining sites and repeated in different mining sites samples. With the help of hierarchisation experts, it was decided to define null limiting values. This option does not erase completely the incomparability relation, but in the most cases, it limited them or it transformed the incomparability relation in a relation of preference or indifference.

Thus, between 2005 and the end of 2007, the Screening did not meet any incomparability situation that could have stopped the on-going studies. All these incomparability cases, ELECTRE's method richness, have been detailed by experts in order to finally class these sites.

2.4. Synthetic representation of the Screening hierarchisation

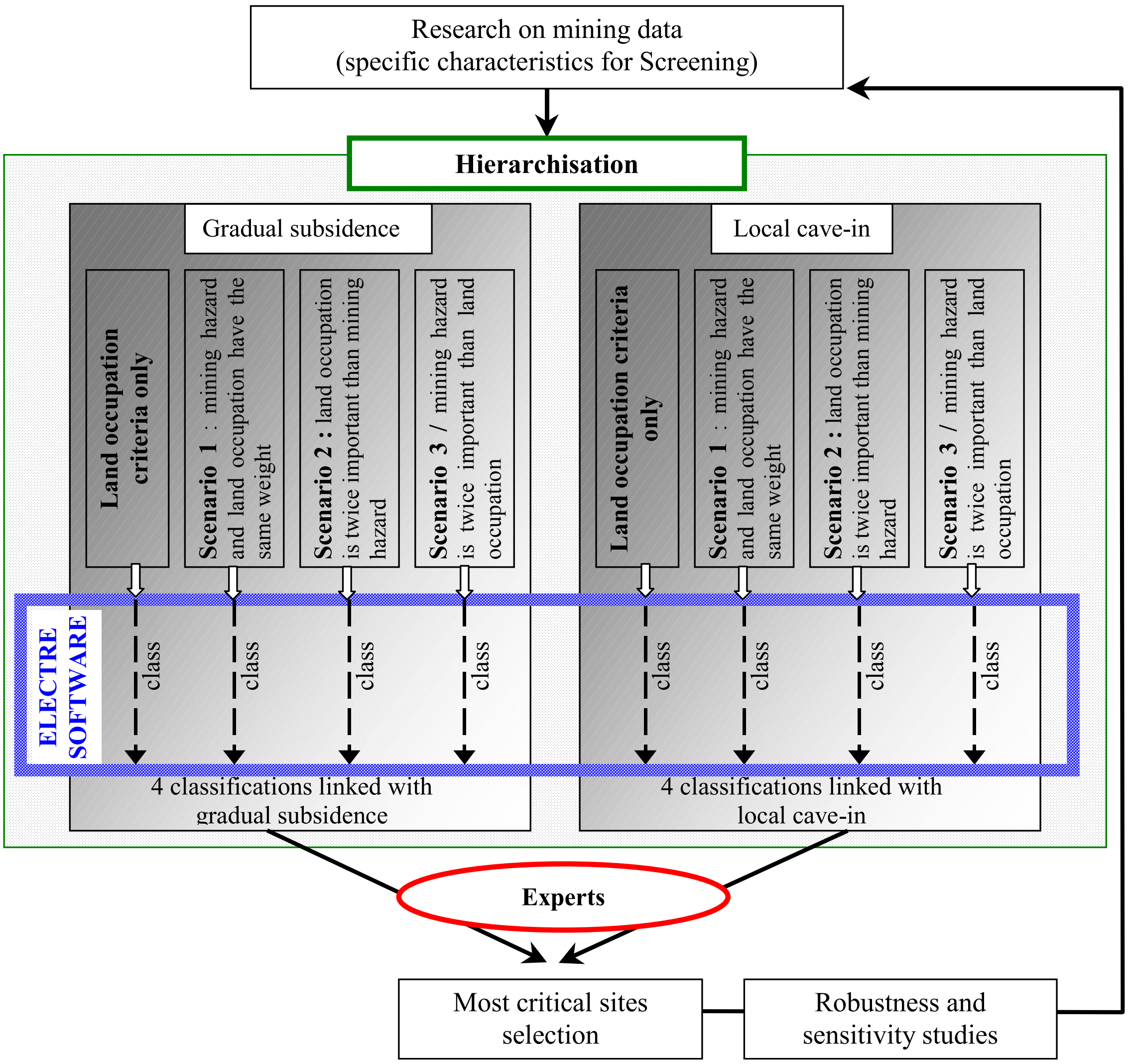

Figure 1. Synthetic representation of the Screening hierarchisation

The applied final hierarchisation process is divided in three stages (Figure 1) :

- first stage where mining sites are characterised in order to describe their mining hazard criteria (local cave-in and gradual subsidence) and their land occupation criteria ;
- second stage, during which eight different classifications are carried out :

    - for the mining sites exposed to a gradual subsidence : one classification linked with land occupation and three classifications corresponding to the three hazard scenarii defined before (§ 2.2.3.2) ;
    - four same classifications for mining sites exposed to local cave-in.
- third stage where the hierachisation results are studied by the experts. These results ought to help them to select the most critical sites. For these specific sites, a simplified risk evaluation and a cartography are undertaken systematically ;
- last stage, fulfilled only during the validation of methods and tools, where the robustness and the sensitivity of the hierarchisation process are improved.

3. Validation of the method and the tools of hierarchisation

3.1. Application to well-known mining sites

In 2005, Provence Alpes Cote d'Azur region (south of France, PACA) was in advance respect to mining database construction. Moreover, many mining sites have been studied for MRPP. In this region, the Regional Departments of Industry, Research and Environment (DRIRE), managing technical and administrative supervision of mining and post-mining activities, was interested in the Screening results. It was agreed to improve the hierarchisation Screening method in PACA.

This validation followed two goals :

- to check whether the classification based on the hierarchisation tool corresponds to the selection of the most critical sites agreed by the DRIRE and the experts ;
- to carry out hierarchisations with MRPP sites and to analyse their risk levels. Note that these sites were not initially included in the Screening (Ministry request).

3.1.1 PACA mining sites

Six MRPP sites have been defined in PACA :

- two sites, called "Gardanne est" et "Gardanne ouest", representing the two main coal exploitations in Provence (Bouches-du-Rhône) ;
- sulfur "Camoins" site (Bouches-du-Rhône) ;
- the lead-zinc-fluorite exploitation of "Cogolin" (Var) ;
- lignit site of "Bois d'Asson" (Alpes-de-Haute-Provence) ;
- coal site of "la Tour" (Hautes-Alpes).

There are one hundred and fifty-three mining sites in PACA (without the previous six MRPP sites) :

- eighty-eight mining sites have been "eliminated" (being either far away from any surface structure or without any risk of surface instability) ;
- the others sixty-five mining sites :
    - are essentially flat exploitations (approximately 60 % of them) ;
    - approximately 80 % of mining sites present a minimum depth lower than 50 m ;

- maximal values of deformation criteria and land occupation nature (one of the most important criteria) have never been encountered ;
- land occupation nature is essentially insulated constructions (40 %), the sectors with potential constructions (20 %) and suburban sectors (15 %).

3.1.2 Hierarchisation results analysis

3.1.2.1 Land occupation hierarchisation

The mining sites with the most important values on the most significant criteria (land occupation nature and stakes area) are well localised in the most risky rows : row 1 to 13, on twenty-two levels in the whole.

The position of the six last mining sites (the less risky sites) is the consequence either of weak values on land occupation criteria (null value) or of the weak areas of stakes.

To precise this group of criteria, the experts have decided to study the sensibility stakes area criterion because it seems to have a direct effect on the classification (§ 3.2).

3.1.2.2 Mining risk hierarchisation

Mining sites with the highest values of minimum depth (one of the most efficient criteria for local cave-in) are well localised in the less risky levels : rows 22 to 29, on twenty-nine levels in the whole. This criterion allows to insulate mining exploitations where the workings are not near surface so less critical for local cave-in. On the other hand, there are too many sites with the highest value on these criteria and thus it can not discriminated the most risky sites in the first rows. The criterion of opening seems to be more effective in this regard. Thus, the experts have decided to replace the criteria “opening “and “minimum depth” by a single criterion : H_{min}/opening, more effective in term of classification linked with local cave-in hazard.

Taking into account these elements, mining risk criteria seem to be correctly defined. However, the sensibility analysis of the maximum depth was decided to be performed, this criterion was not really “limpid” (§ 3.2).

3.1.2.3 Comparison with DRIRE and experts selection

DRIRE has carried out his own selection of the most critical sites in PACA.

The first eleven rows proposed by the ELECTRE’s software (on twenty-two rows total for the local cave-in classification), reproduce the whole sites preselected by the DRIRE. These sites are in gray in the following table (Table 7).

In these first eleven rows, the mining sites which are not preselected are :

- the mining sites over-estimated by the most efficient criteria ;
- mining sites not considered by the DRIRE in its preselection (because of the complexity of this work).

The same kind of analysis has been drawn for the gradual subsidence.

These results show that the classification based on the hierarchisation tool, corresponds to the selection of the most critical sites agreed by the DRIRE and the experts

Table 7. Extract from the hierarchisation given by ELECTRE software (linked with local cave-in PACA).
The mining sites that are in gray are those selected by DRIRE before the implementation of the hierarchisation method

scenario 1		scenario 2		scenario 3	
Site number	**Row**	**Site number**	**Row**	**Site number**	**Row**
"13_256"	1	"13_256"	1	"13_232"	1
"84_039"	1	"84_039"	2	"84_039"	2
"13_232"	2	"83_054"	2	"13_013"	3
"13_236"	3	"13_232"	3	"13_236"	3
"13_016"	3	"13_013"	3	"13_256"	4
"83_065"	3	"83_065"	3	"06_026"	5
"13_013"	4	"06_026"	4	"83_040"	5
"06_026"	4	"83_076"	4	"83_065"	5
"83_040"	5	"13_236"	5	"13_016"	6
"83_076"	5	"13_016"	5	"83_076"	7
"06_029"	6	"83_040"	5	"06_025"	8
"83_041"	6	"13_024"	6	"13_229"	8
"06_025"	7	"06_025"	6	"83_041"	8
"83_054"	7	"06_029"	6	"06_028"	9
"13_024"	8	"83_041"	6	"13_024"	9
"83_045"	8	"83_045"	6	"83_012"	9
"06_028"	9	"13_022"	7	"83_050"	9
"13_022"	10	"06_028"	7	"06_029"	10
"13_229"	10	"83_012"	7	"83_045"	10
"83_012"	10	"83_032"	8	"13_014"	11
"13_014"	11	"13_229"	9	"13_022"	11
"83_049"	11	"83_038"	9	"83_003"	11
"83_050"	11	"13_014"	10	"05_014"	12
…	…	…	…	…	…
…	…	…	…	…	…

3.2. Sensitivity and robustness analysis

3.2.1 Area of the stakes

This criterion seemed to have a significant effect on the risk classification. To improve this hypothesis, three new hierarchisations have been decided with three new weights for the area of stakes : 13, 17, 21 and 25 (weight defined initially). The results have been presented in a graph where each mining site (X-axis) is correlated with its four rows obtained in four hierarchisations (in Y-axis) :

- the rows of each mining site are not really varying by different weights, the most important variation is approximately two rows in twenty-two rows in total. These variations follow the expected sense : the risk decreases when the criterion “weight” decreases (sites 06_029, 13_106 and 83_054 with the most important areas of stakes).
- regarding the whole mining panel, the classifications, from the most risk to the less risky sites, seem to be similar using different weights. Only the site 13_013 goes up significantly in the classification towards the most risky sites when the criterion weight decreases (row 4 for weight 25 and row 2 for weight 13). This situation is natural because this site presents critical values for the significant criteria (maximal value opening of the sample) and an average stakes area.

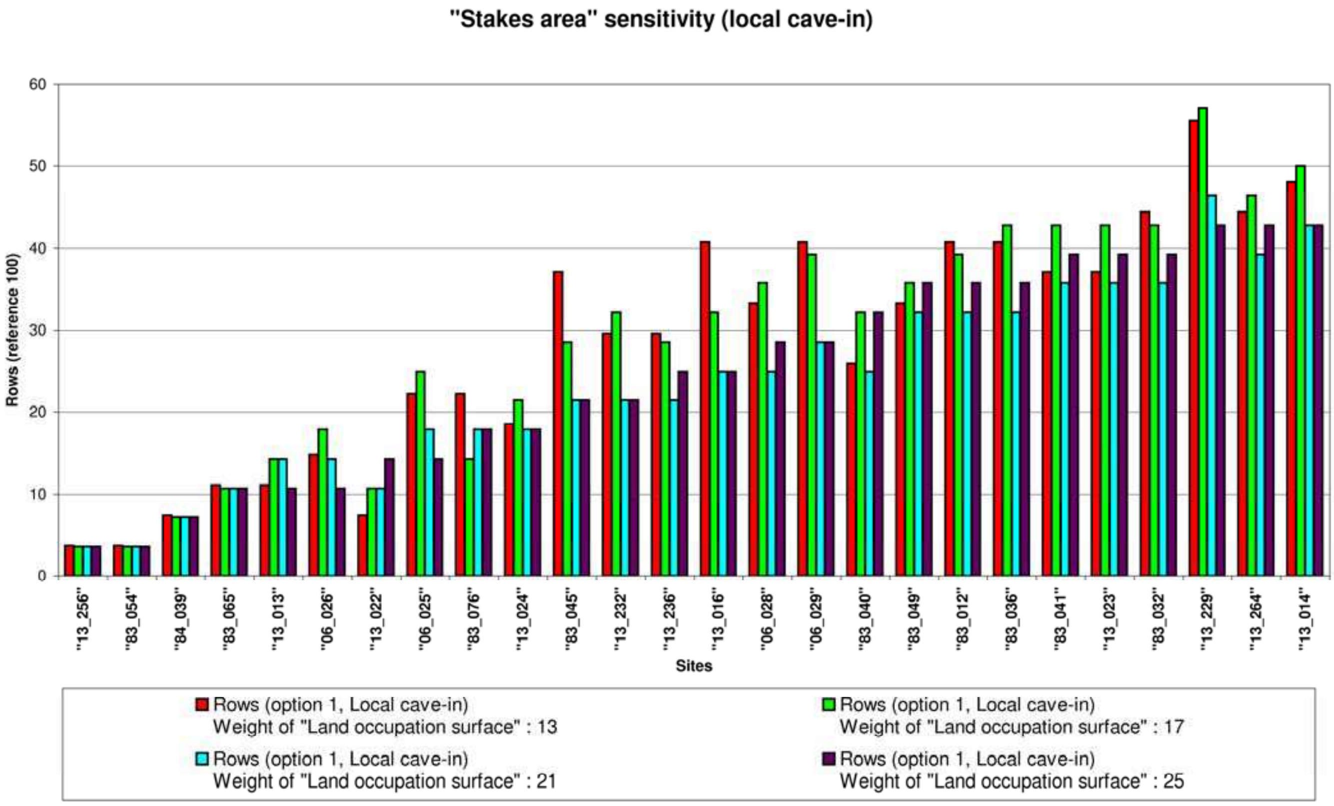

Figure 2. Sensitivity of the stakes area

3.2.2 Maximum depth

Four new hierarchisations have been carried out, with four new weights for maximum depth : 6, 8, 11 (first weight), 13 and 15. The classifications show that these different weights do not modify significantly the results. Moreover, maximum depth seems to distinguish the mining sites having an important workings density at low depth. Indeed, the mining sites presenting the lowest maximum depths (less than 50 m), go up, towards the most risky sites, when the weight of the criterion increases.

3.3. Robustness analysis

To improve robustness, it was agreed to integrate MRPP sites in the mining sites of PACA and then analyse their rows. Table 8 presents these results :

- the integration of new mining sites in the sample does not modify the most critical selection sites (lowest rows). Moreover, the precise order is slightly modified but the ten most risky sites before the integration always remains among the most risky after the integration of the MRPP sites ;
- MRPP sites are placed in the top of the classification, that is to say among the most risky sites, corroborating the DRIRE choice and opinions (among the 10 first rows for local cave-in and among the eight first rows for gradual subsidence). The only MRPP site appearing further in the classification is “Bois d’Asson”. This classification finds its logical explanation because of the low value of land occupation (insulated constructions) which is one of the lowest values observed in PACA. The characteristics of these six sites did classify these sites among the most risky, at least for five of them. Indeed, “Camoins”, “Cogolin”, “Gardanne Est” et “Gardanne Ouest” and “la Tour”, most probably, would have been selected for a quick study in the

Screening. “Bois d’Asson”, going down in the classification, would not have been selected. The person who has made this MRPP confirms this results, “Bois d’Asson”, would not have been studied by MRPP, because of its low risk level, compared to other mining sites in PACA.

Table 8. Extract from hierarchisation results (before and after MRPP site integration)

Hierarchisation scenario 1 (local cave-in)			
Site number	**Rows without MRPP sites**	**Site number**	**Rows with MRPP sites**
"13_256"	1	**"Gardanne Est"**	1
"84_039"	1	"13_256"	2
"13_232"	2	**"La Tour"**	2
"13_236"	3	"13_232"	3
"13_016"	3	"84_039"	3
"83_065"	3	"13_013"	4
"13_013"	4	"83_065"	4
"06_026"	4	**"Camoins"**	4
"83_040"	5	"13_016"	5
"83_076"	5	**"Cogolin"**	5
"06_029"	6	"83_040"	6
"83_041"	6	"13_236"	7
"06_025"	7	"06_026"	8
"83_054"	7	"83_076"	9
"13_024"	8	"06_029"	10
"83_045"	8	**"Bois d'Asson"**	10
…	…	…	…

Hierarchisation scenario 1 (gradual subsidence)			
Site number	**Rows without MRPP sites**	**Site number**	**Rows with MRPP sites**
"84_039"	1	**"Gardanne Est"**	1
"13_256"	2	"84_039"	2
"13_232"	3	"13_256"	3
"13_236"	4	"13_232"	4
"13_013"	4	**"Camoins"**	5
"13_016"	5	**"Gardanne Ouest"**	6
"06_026"	5	**"La Tour"**	6
"06_029"	6	"13_013"	7
"83_040"	6	"83_040"	8
"83_041"	6	**"Bois d'Asson"**	8
"83_045"	6	"13_236"	9
"13_014"	7	"06_026"	9
"83_065"	7	"13_016"	10
…	…	…	…

4. Conclusions

In France, mining data are usually centralised at a regional level under the DRIRE responsibility. To optimise the results reliability and the work effectiveness, the Screening process has been performed, in France, region by region. This choice also allows to give to the Ministry the expected results in due time. When the regional studies will be finished, one final hierarchisation at a national level will be planned.

At the end of 2007, approximately one thousand and hundred mining sites were classified in seventeen different regions. The most important regions were Rhones-Alps with two hundred and one hierarchised sites, Auvergne with one hundred and forty-six hierarchised sites and Languedoc-Roussillon with one hundred and forty-three hierarchised sites.

The hierarchisation method and tools fulfilled the expected objectives. They provided an effective help to the selection of the critical mining sites. The rough results of these hierarchisations have never been used directly ; they required a fine and accurate analysis in order to, in particular, insulate, in the selection suggested by the tool, the sites which had been considered from a safety point of view.

The developed hierarchisation method (and tool) can be described as “adapted” to the issues linked with the Screening. The next stage is to apply this method to the whole national mining sites ; a difficult operation that raises the question of the method robustness regarding the sample extension (more than thousand mining sites).

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